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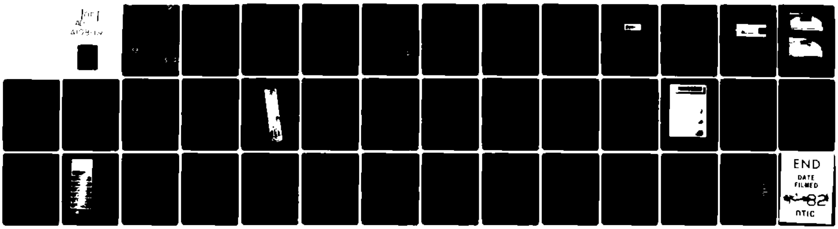

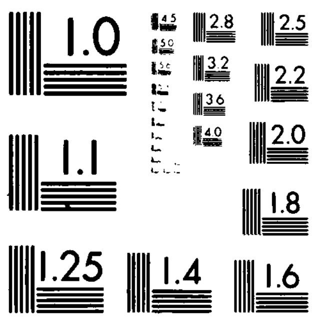

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TECHNICAL REPORT ARBRL-TR-02377

CHARACTERIZATION OF IGNITION SYSTEMS FOR BAGGED ARTILLERY CHARGES

Thomas C. Minor

October 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECHNICAL REPORT ARBRL-TR-02377	2. GOVT ACCESSION NO. AD-A108	3. RECIPIENT'S CATALOG NUMBER 119
4. TITLE (and Subtitle) Characterization of Ignition Systems for Bagged Artillery Charges		5. TYPE OF REPORT & PERIOD COVERED Technical Report January - July 1980 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas C. Minor		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BLI Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Armament Research & Development Command U.S. Army Ballistic Research Laboratory ATTN: DRDAR-BL Aberdeen Proving Ground, MD 21005		12. REPORT DATE October 1981 13. NUMBER OF PAGES 37
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Interior ballistics	Flamespread
Interior ballistics modeling	Centercore igniters
Interior ballistics model validation	M203 Propelling Charge
Two-phase flow	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) jmk

The past decade has witnessed substantial effort in modeling the gun interior ballistic cycle as an unsteady, two-phase flow problem. Recently, emphasis has been placed on extending modeling expertise to account for the multi-dimensionality of the problem and improving the constitutive relationships embedded in the models. As the models become more complex, the requirement for accurate, well-defined data to use for computer code input and model verification becomes increasingly urgent. In particular, one critical element, identified in many past studies, is the functioning of the igniter system, since it has been shown that events that occur during ignition and flamespread can seriously impact overall charge performance. Indeed, the sophisticated models we see today were largely precipitated by a series of gun ammunition malfunctions, which were in many cases attributable to ignition-related causes. Variability of performance is especially of concern in bagged artillery charges, which employ low-pressure igniters. Thus we are faced with the dual task of providing relevant data to the modeling community and presenting the charge designers with the information and tools to arrive at safe and reliable ignition systems.

We report herein data to support these twin objectives, obtained in a new apparatus at the Ballistic Research Laboratory employing a transparent chamber mimicking that of the 155-mm howitzer. Data obtained include chamber pressures, flamespread during igniter functioning and early charge ignition, charge component behavior, and charge motion. Specially built charges, made from US Army 155-mm, M203, Zone 8S components, employed plexiglass windows to permit direct visualization of the details of igniter system performance within the charge. Tests reported comprise a complete matrix, the parameters of which include live and inert basepads, snakes, and propellant in a centercore-ignited charge. In addition, some very preliminary results of ignition and early flamespread in a multiple-increment charge, obtained in the same fixture, are reported. Conclusions are drawn regarding: the ignition transfer between combustible charge constituents, and resultant chamber pressurization; the influence of ullage and non-energetic charge components; charge motion; and the possible gas-phase combustion of pyrolized products.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

A number of theoretical and experimental studies have been undertaken to better understand the phenomenology of the gun interior ballistic cycle. Considerable progress has been made, largely as a result of the recognition of the interior ballistic cycle as an unsteady, two-phase flow problem, one in which events occurring during ignition and flamespread may have substantial impact on subsequent stages of the process. Unfortunately, this realization has come at the expense of several gun ammunition malfunctions[1-3], many of which had their origins in events occurring during the ignition and early flamespread portions of the cycle. The problem in designing safe charges has become more acute over recent years as we strive for ever higher ballistic performance. Fortunately, we now have available models[4,5] that take away some of the art that was formerly associated with charge design, and put the process on a much more solid physical foundation. The models have in the past been quite successful in simulating the rigidly confined, high-pressure-ignited cased ammunition charges, but have enjoyed moderate success in modeling bagged charges only with unwarranted manipulation of input data. These models are currently being extended to new levels of sophistication through the introduction of multi-dimensionality and improved constitutive relationships. As the demands for charge performance increase, and as the models become increasingly complex, it is imperative that we further our understanding of all phases of the interior ballistic cycle, particularly the crucial ignition period.

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[1] *D. W. Culbertson, M. C. Shamblen, and J. S. O'Brasky, "Investigation of 5" Gun In-Bore Ammunition Malfunctions," NWL TR-2624, Naval Weapons Laboratory, Dahlgren, VA, December 1971.*

[2] *I. W. May, E. V. Clarke, and H. Hassmann, "A Case History: Gun Ignition Related Problems and Solutions for the XM198 Howitzer," Proceedings of the International Symposium of Gun Propellants, Picatinny Arsenal, October 1973.*

[3] *P. J. Olenick, "Investigation of the 76-mm/62 Caliber Mark 75 Gun Mount Malfunction," NSWC/DL TR-3144, Naval Surface Weapons Center, Dahlgren, VA, October 1975.*

[4] *P. S. Gough and F. J. Zwarts, "Some Fundamental Aspects of the Digital Simulation of Convective Burning in Porous Beds," AIAA Paper No. 77-855, AIAA/SAE 13th Propulsion Conference, July 1977.*

[5] *E. B. Fisher, "Quality Control of Continuously Produced Gun Propellant," Report No. SA-5913-X-1, Calspan Corporation, Buffalo, NY, August 1977.*

A. PHENOMENOLOGY OF THE GUN INTERIOR BALLISTIC CYCLE

A better understanding of the process is attained with a discussion of the performance of an idealized propelling charge, shown in Figure 1. An igniter stimulus, whose intensity and distribution are system dependent, is applied to the propellant, venting hot combustion gases into the bed. These gases heat neighboring propellant grains to ignition, and the gases from this combustion join those of the igniter to produce a convectively driven ignition wave, resulting in flamespread through the charge. The packed propellant presents resistance to the flow of these gases, which can lead to large pressure gradients within the charge, and perhaps even induce substantial movement of the propellant. Especially in charges ignited at the base with ullage concentrated at the forward end of the charge, considerable velocities can be attained by the solid phase. Stagnation at the projectile base then may be accompanied by high local pressurization, leading to the formation of traveling axial pressure waves, and perhaps even grain fracture[6].

Let us now turn this analysis to a real charge, such as the 155-mm, M203, Zone 8S, Propelling Charge. The charge, schematically illustrated in Figure 2, consists of a single increment, packaged in a bag, and is centercore-ignited. The intended mode of ignition for this charge calls for the primer to vent its hot gases onto a basepad, which then burns and

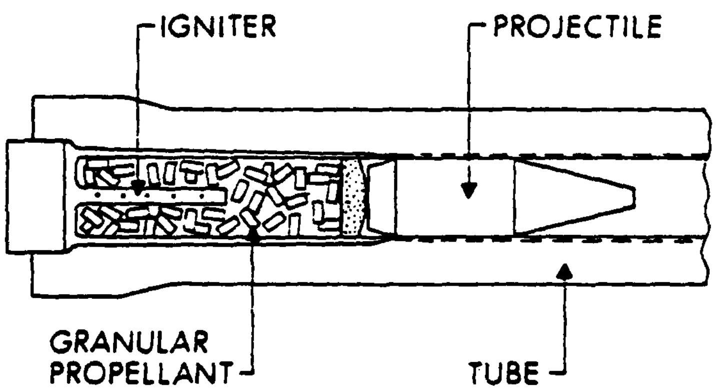

Figure 1. Idealized Propelling Charge

[6] *A. W. Horst, I. W. May, and E. V. Clarke, "The Missing Link Between Pressure Waves and Breechblows," 14th JANNAF Combustion Meeting, CPIA Publication 292, Vol. II, pp. 277-292, December 1977.*

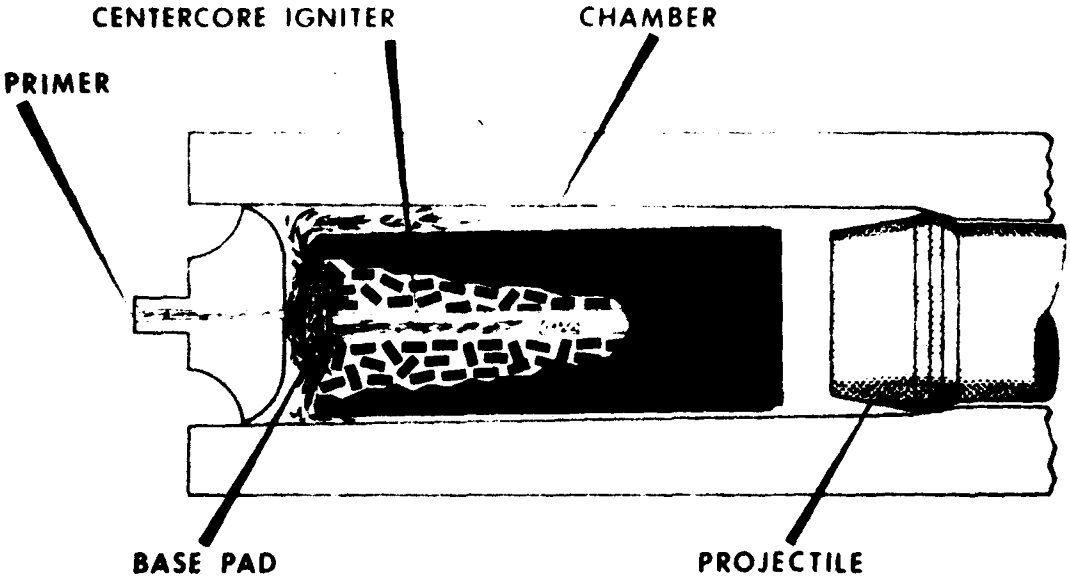

Figure 2. Phenomenology - Single-Increment, Centercore-Ignited Charge

serves as an ignition transfer to a pouch (the "snake") of black powder contained within the nitrocellulose centercore igniter tube. Rapid flame propagation through the snake and centercore, with its radial venting of hot gases, should then assure uniform axial ignition of the charge. A closer examination, however, reveals some of the possible flaws in this chain. The charge is undersized with respect to the internal dimensions of the chamber, creating ullage radially, in front of the charge, and between the spindle and charge (standoff). This allows for a variety of complex flows depending upon the initial loading configuration. The centercore tube does not necessarily align with the primer output upon loading, reducing the efficiency of ignition transfer from primer to centercore. In fact, the burning basepad may locally ignite propellant grains at the rear of the charge, producing a competition between ignition of the charge by the centercore or by locally burning propellant at the base of the charge. There are indications that an ignition site is not well-established, and that ignition may actually take place downstream in a wake of pyrolized products[7], and that the centercore burns through in a preferred region[8], rather than dispensing igniter products uniformly

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[7] *A. Birk and L. H. Caveny, "Ignition of Solid Propellants Under Transient Flow Conditions," 16th JANNAF Combustion Meeting, CPIA Publication 308, Vol. I, pp. 515-540, December 1979.*

[8] *K. J. White and A. W. Horst, "Black Powder Flamespreading Characteristics," Proceedings of Seventh International Pyrotechnics Seminar, pp. 757-770, Illinois Institute of Technology Research Institute, July 1980.*

along the charge. The radial ullage may serve as a path of least resistance, which igniter products take instead of percolating into the lower porosity propellant bed and ignition system. The forward ullage not only provides a sink for these gases, but also creates a distance over which the solid propellant can be accelerated to impact the projectile base. The charge casing, a cloth bag with parasitic components such as wear-reducing and decoppering liners, and flash reducer pads attached to it, is of grossly nonuniform strength and permeability, giving rise to a host of scenarios of gas flow, bag rupture, propellant motion, and the like. And, lastly, further variability is introduced by the igniter system itself, since it operates at low pressures and may not reproducibly drive the ignition of the rest of the charge.

The variability and complexity inherent in bagged charge performance is not limited to the single-bag, centercore-ignited situation. Consider a lower-performance, multi-increment, base-ignited charge, as illustrated in Figure 3. The intended method of ignition here is different from that just discussed in that a basepad supplies the sole ignition impetus, but since this is a low-loading density charge, high-level pressure waves are historically not of concern. Yet this charge suffers from many of the same problems as its single-bag counterpart. This charge is also considerably smaller than the chamber, and the variety of complex flows discussed earlier obtain here. Likewise, parasitic components attached to and embedded within the charge may serve to block the passage of igniter and propellant gases. A multiple-increment charge may have more than one granulation propellant, and the localized ignition and brisant combustion of a fine-web base-increment propellant can induce pressure waves and perhaps even considerable movement of relatively massive, entire packages of propellant. So, in addition to the problems usually associated with ignition-induced pressure waves, such as gun safety, the effect of the impact of large quantities of propellant on the projectile base on the projectile's safety and performance is now of concern.

B. THE REQUIREMENT FOR EXPERIMENTATION

Our brief survey of the early performance of large-caliber, bagged artillery charges indicates that the details of the events during this period are poorly known, and even more poorly quantified. This is a critical shortcoming to the charge designer, who needs this understanding to design safe, reliable, and cost effective charges. Just as important, those who model the detailed, unsteady, multi-dimensional, two-phase flow characteristics of the gun interior ballistic cycle have an acute need for these type of data. The experimentalist is called upon not only to provide the modeler with the scope of the relevant physical processes to be included in a phenomenologically complete model, but also to provide the data against which the model predictions are judged. While continued development and sophistication of these models, such as extensions to multiple dimensions, will no doubt improve the quality of the predictions,

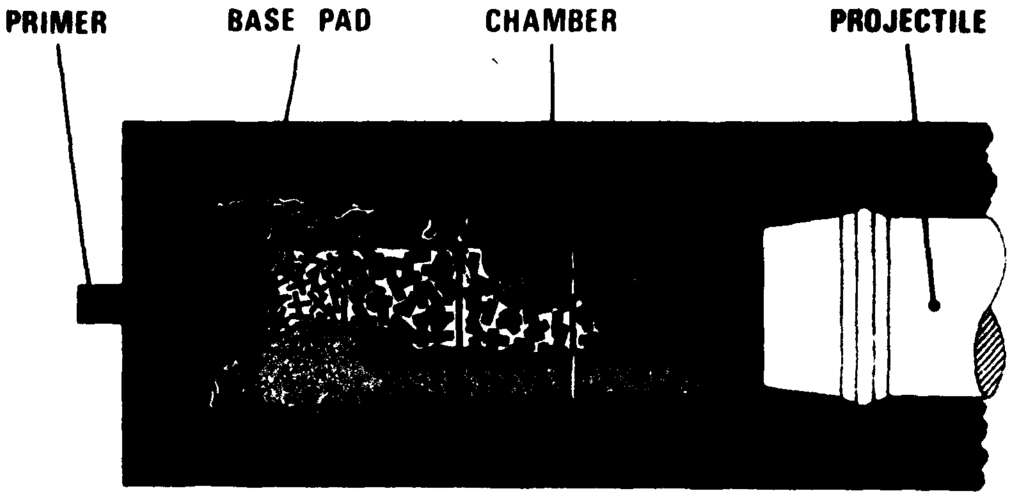

Figure 3. Phenomenology - Multi-Increment, Base-Ignited Charge

it hardly seems likely that they will enjoy complete success without a detailed treatment of the complex interplay of all charge components which affect ignition, including the igniter proper, ullage, bag and jacket materials, liners, and flash reducer pads.

II. EXPERIMENTAL

A. APPARATUS

The apparatus used to conduct a variety of studies at the Ballistic Research Laboratory of the detailed phenomenology of propelling charges is shown in Figures 4 and 5. This apparatus is the second generation of

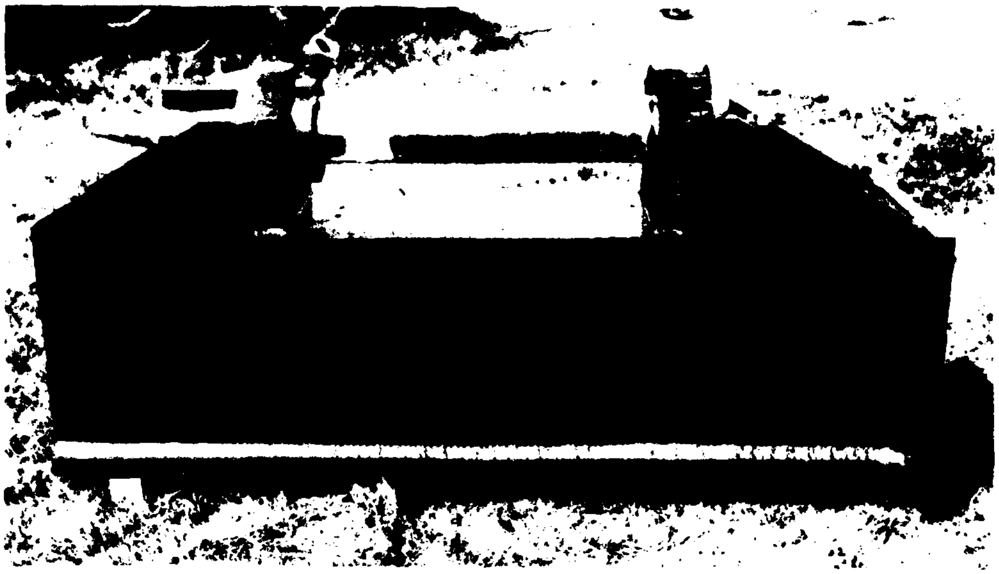

Figure 4. 155-mm Howitzer Simulator, Plastic Chamber

Figure 5. 155-mm Howitzer Simulator, Fiberglass Chamber

a fixture we previously used[9-11], which was based on a similar setup at the Naval Surface Weapons Center, Dahlgren (NSWC/DL)[12-14]. The massive mount, constructed of armor plate, accepts either plastic chambers (Figure 4) or axially reinforced, filament-wound fiberglass chambers (Figure 5). The plastic chambers are commercially available cast acrylic tubing with nominal inner and outer diameters of 165 mm and 191 mm, respectively. The clear plastic offers much better visibility of the events transpiring within than does the fiberglass, but it fractures at significantly lower pressures. The pressure limit for these tubes has been found to be variable from sample to sample, and is pressure-rise-rate dependent. The fiberglass chambers are manufactured by NSWC/DL, and are wound on a mandrel to the interior dimensions of the 155-mm, M199 cannon chamber. The muzzle end of the chamber is closed by a projectile seated in a section of gun tube machined to the dimensions of the M199. The projectile may include onboard instrumentation. The breech end of the apparatus is closed by one of four spindles: the mushroom configuration of the M199 or M185, or flattened-face versions of each. As Figure 6 shows, each of the spindles accepts three Kistler 607C piezoelectric pressure transducers, and an array of five additional pressure gages can be mounted in the fiberglass chamber sidewall along its axis. Strain patches may be affixed to the cases to monitor stresses induced by solid-phase phenomenology.

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[9] *A. W. Horst and T. C. Minor, "Ignition-Induced Flow Dynamics of Bagged-Charge Artillery," Proceedings of 4th International Symposium on Ballistics, American Defense Preparedness Association, October 1978.*

[10] *T. C. Minor, A. W. Horst, and J. R. Kelso, "Experimental Investigation of Ignition-Induced Flow Dynamics in Bagged-Charge Artillery," 15th JANNAF Combustion Meeting, CPIA Publication 297, Vol. I, pp. 61-83, February 1979.*

[11] *T. C. Minor and A. W. Horst, "Experimental Studies of Two-Phase Flow Dynamics in Gun Propelling Charges," Proceedings of the 10th ICT Internationale Jahrestagung, pp. 191-222, Fraunhofer-Institut für Treib-und Explosivstoffe, June 1979.*

[12] *J. L. East and D. R. McClure, "Experimental Techniques for Investigating the Start-up Ignition/Combustion Transients in Full-Scale Charge Assemblies," 11th JANNAF Combustion Meeting, CPIA Publication 261, Vol. I, pp. 119-139, December 1974.*

[13] *J. L. East and D. R. McClure, "Experimental Studies of Ignition and Combustion in Naval Guns," 12th JANNAF Combustion Meeting, CPIA Publication 273, Vol. I, pp. 221-257, December 1975.*

[14] *W. R. Burrell and J. L. East, "Effects of Production Packing Depth and Ignition Techniques on Propelling Charge Reaction and Projectile Response," NSWC/DL TR-3705, Naval Surface Weapons Center, Dahlgren, VA, April 1978.*

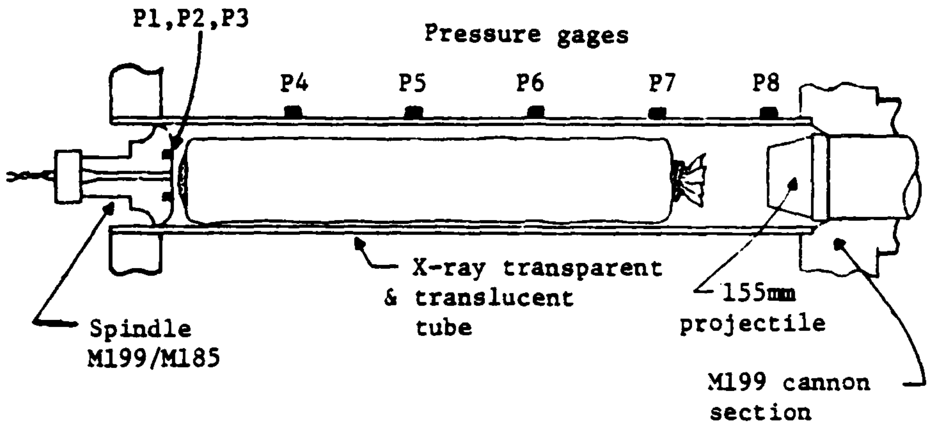

Figure 6. Schematic of 155-mm Howitzer Simulator

Photographic data are recorded with a Hycam 40, high-speed, 16-mm camera. For the tests reported here, the data were recorded on Kodak Ektachrome 7241 film at a framing rate of approximately 5200 pictures per second. A 1-kHz timing signal was placed on the film by electronics internal to the camera, and the firing fiducial (time at which the firing voltage is applied to the gun) was also placed on the film to aid in correlation of the film data with other data. A mirror was positioned behind the mount to allow simultaneous recording on a single frame of events occurring on both sides of the chamber.

Flash radiography permits measurement of location, and hence movement, of the solid phase within the X-ray transparent chamber. While X-rays have not yet been used in conjunction with this apparatus, such a 300 keV capability will soon be available. For each firing, two radiographs will be recorded on a single cassette placed opposite the chamber from the X-ray heads. The radiographs will be recorded on Kodak XR-5 film using image intensifier screens. Suitable shielding, such as aluminum sheeting, will be used to protect the cassette from the blast.

Figure 7 depicts the system for experiment control, data acquisition, and data reduction. The Ballistic Data Acquisition System (BALDAS) performs these tasks, driven by a PDP 11/45 mini-computer. By starting a programmed sequence timer, BALDAS controls the firing of the high-speed camera and enables an X-ray trigger circuit. At the appropriate time, BALDAS exercises an in-line, five-step, calibration for each data channel, then fires the cannon and acquires and digitizes analog data through a 16-channel, 10-bit, 24-K word analog-to-digital converter. At the same time, a backup analog record is made on a 14-channel FM tape recorder. BALDAS-resident digital counters record the time of the firing fiducial and other events, such as an X-ray trigger pulse.

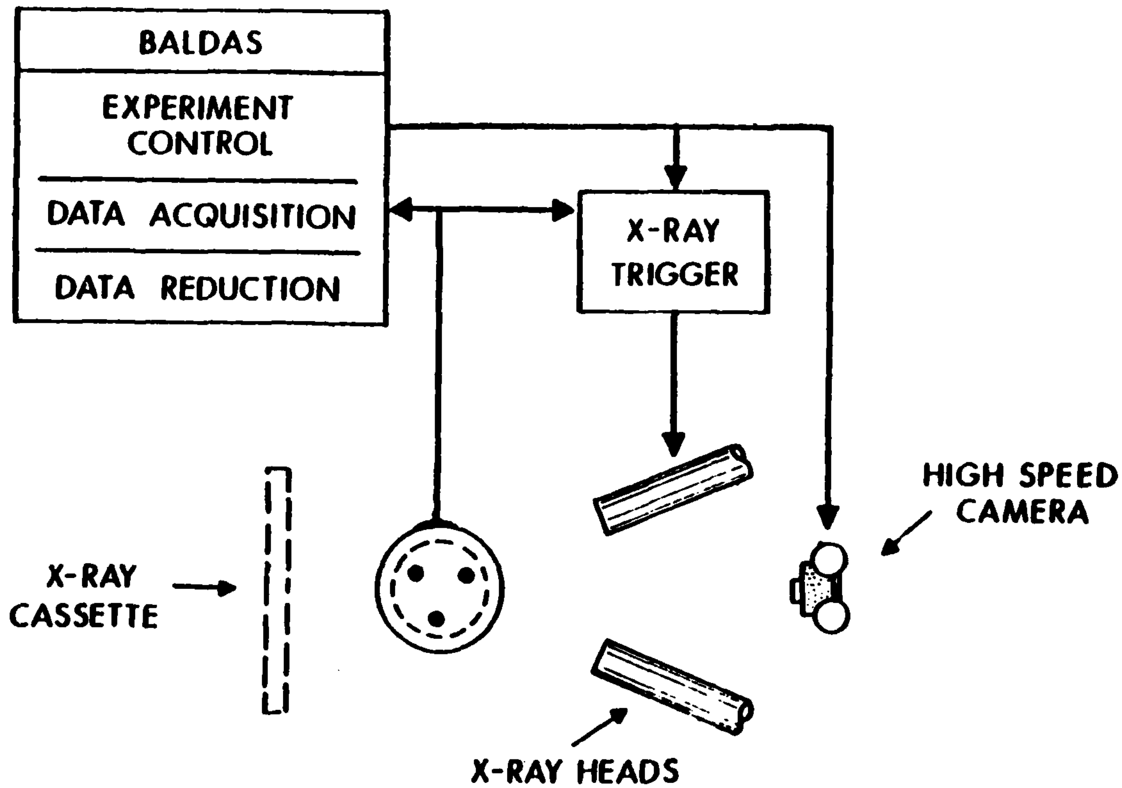

Figure 7. Instrumentation, Experiment Control, and Data Acquisition for 155-mm Howitzer Simulator

After the data are acquired, BALDAS calibrates the data via a second-order, least-squares fit to the calibration staircase, and then reduces the data, through suitably introduced gage constants. Data are displayed on plots or in a point-by-point listing of the digital record.

B. RESULTS

We now turn our attention to the experimental results obtained. We first describe the results obtained in a series of nine, specially built, M203-type charges fired to investigate the very early portion of the functioning of this centercore-ignited charge. We then proceed to describe our first, preliminary results obtained with a 155-mm, multi-increment propelling charge. For each of the shots, data obtained included three pressures recorded in the spindle and high-speed photography. All shots were conducted using the M185-type spindle, with the centrally aligned primer spithole, and the standoff, or distance from spindle face to the rear of the charge, was approximately 25 mm. The primer for each shot was an M82.

1. Charge Design. A photograph of the parent, 155-mm, M203 charge is shown in Figure 8, and Figure 9 shows an exploded view of the modified charges as fired in this study. For easy reference we divide the rounds into three, three-round series:

Series I - live basepad, inert snake and propellant
Series II - live basepad and snake, inert propellant
Series III - fully live charge

All charge components used, including the black powder, but not including the propellant, were from M203 Lot IND 80A 120-003. In Series I, the inert black powder simulant used in the snake was commercially available carbon boiling chips, screened to yield particles of the same size as the Class I black powder in the M203 igniter. In Series I and II, the propellant simulant consisted of inert cylinders with a length of 24.5 mm and a diameter of 10.5 mm. In Series III, live M30A1 propellant, Lot RAD 79E 069960, with a length of 24.3 mm and a diameter of 10.5 mm, was used. Live materials and their inert counterparts were loaded in a similar manner. Since the vagaries of construction made each charge slightly different, loading was done by volume, rather than by weight. The unique feature of these charges was the window embedded in the charge to allow direct visual access to the center of the charge (Figure 9). The window consisted of polished, 13-mm-thick plexiglass, with fourteen tabs cut on one side for insertion into the centercore. The centercore was punctured with 13-mm square holes on 51-mm centers to accept the tabs. The depth of the castellation was such that it did not intrude into the bore of the centercore. During assembly, the edges around the holes in the centercore were sealed with a nitrocellulose glue to prevent low-pressure gas escape. The charges were constructed thusly: the

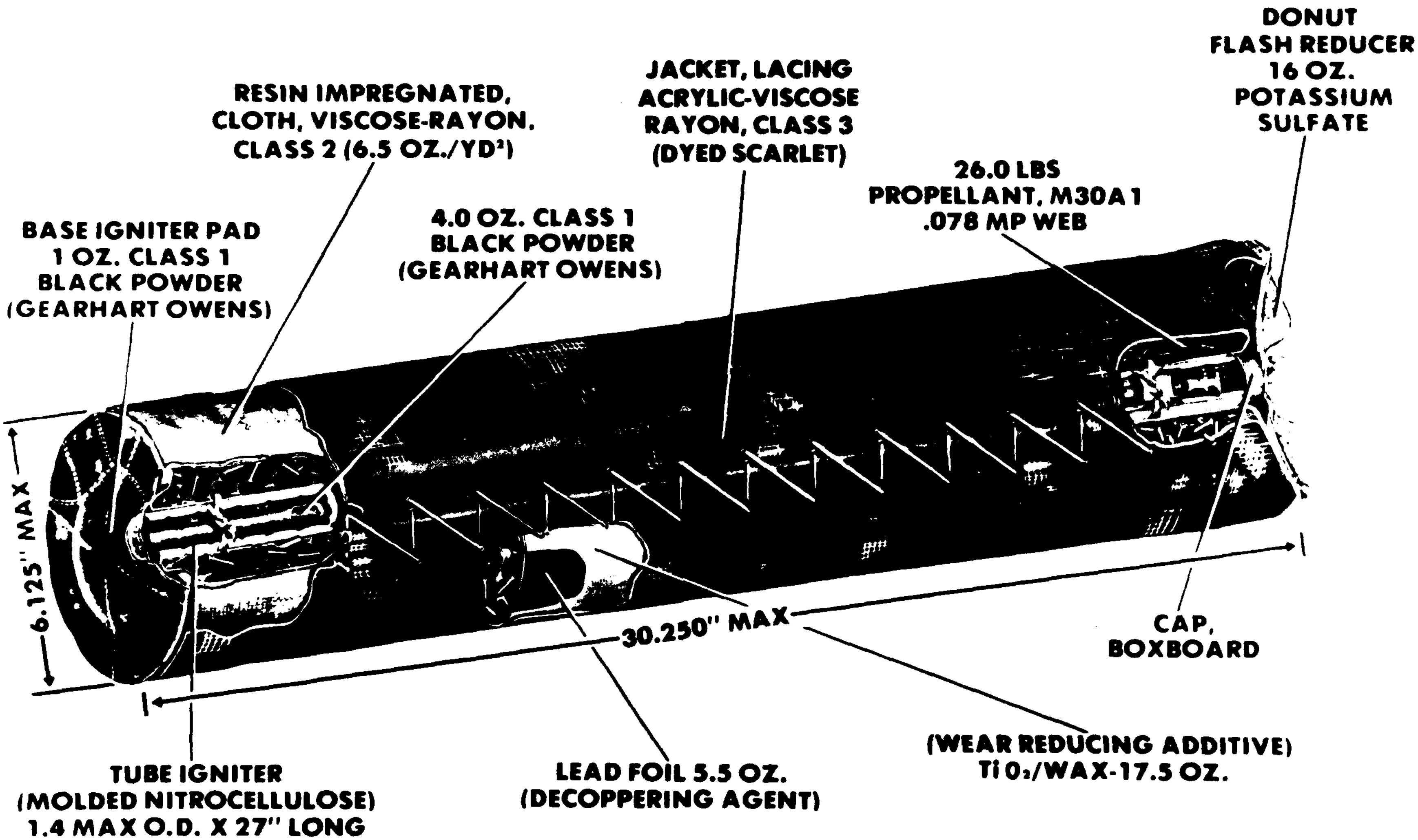

Figure 8. 155-mm, M203, Zone 8S, Propelling Charge

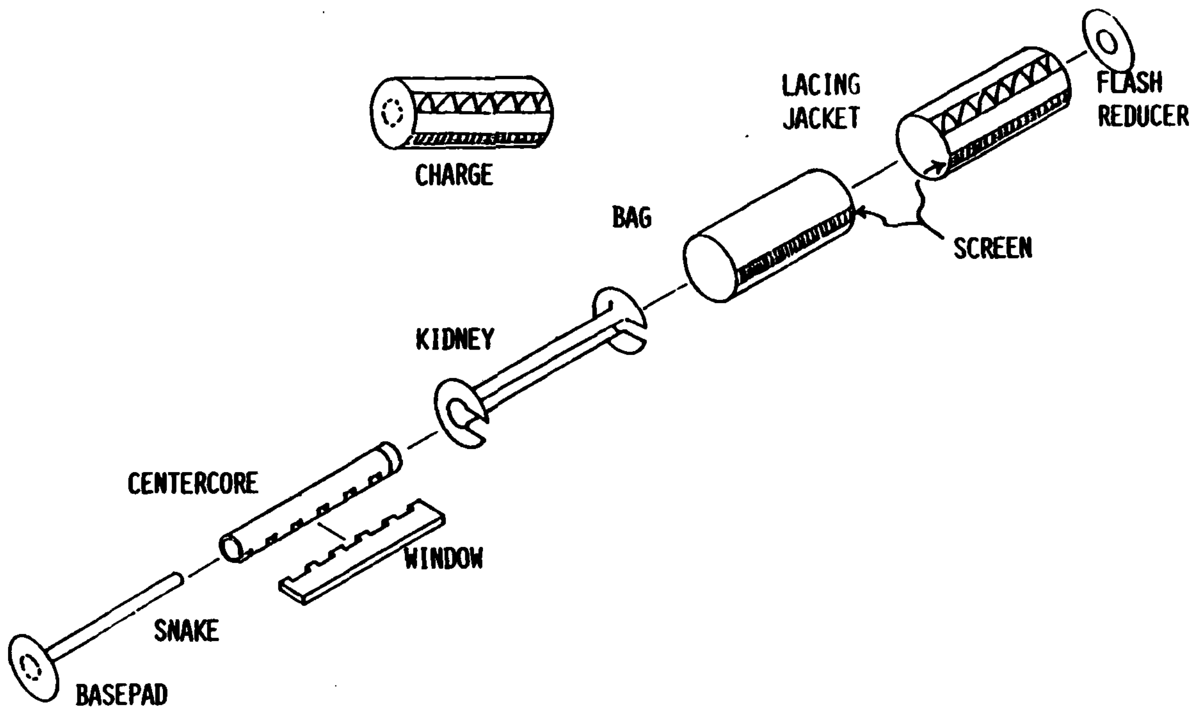

Figure 9. Exploded View - Windowed 155-mm, M203, Zone 8S Propelling Charge

window was glued to the centercore, the igniter assembly was attached to the centercore, the centercore glued inside the kidney, and then the kidney was sewn into the bag. The bag and lacing jacket had previously been modified by the addition of a fine mesh screen to allow visualization of the window. After the jacket was placed loosely about the bag, with due care to the alignment of window and screened areas, the propellant was loaded into the assembly, using a rod to pack it around the window. Finally, the end was sewn closed and the lacing jacket adjusted to nominal M203 dimensions.

A schematic of the multi-zone charges tested is shown in Figure 10. This charge is the concept arising out of the Advanced Development Program for the 155-mm, XM211 Propelling Charge. The XM211 was to be the Army's low-zone charge, covering Zones 3 through 6; the development program was terminated since this investigation. At one point in the program, the base increment, Zone 3, consisted of approximately 1.67 kg of 0.33-mm, single-perforation M1 propellant. Zones 4 through 6 contained, respectively, 0.79, 1.45, and 2.66 kg of 0.97-mm, M1, seven-perforation propellant. Some testing of this charge showed a higher level of pressure waves at Zone 5 than at Zone 6. It was hypothesized that the brisant base increment acted as an extended base igniter, generating sufficient gas to propel the forward increments to impact on the projectile base, perhaps causing grain fracture, and thus augmenting pressure waves. This tendency would be stronger at Zone 5 than at Zone 6, since there is less inertia to overcome at Zone 5, and the distance between the front of the charge and the projectile at this zone is larger than at Zone 6, giving room for higher propellant velocities to be attained.

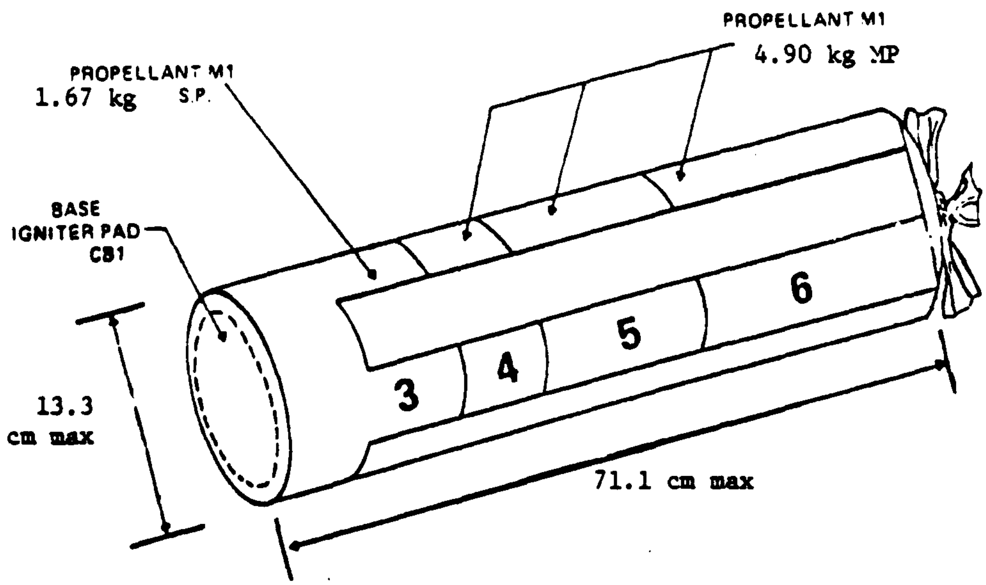

Figure 10. 155-mm, XM211, Propelling Charge - Advanced Development Concept

2. Series I - Live Basepad, Inert Snake and Propellant. All of the M203 igniter charges were conditioned to 20°C and fired in the plastic chamber. In each of the series, we will discuss one shot in detail, giving pressure records and a schematic abstracted from the films, and we will discuss the differences of the other shots from the ones described.

Figure 11 shows the P3 pressure trace from one of the Series I shots, and Figure 12 shows a schematic abstracted from the film record. Areas of luminosity are stippled. The times are referenced to that at which the firing voltage was applied to the gun. Of note here is evidence of the primer seen on the P3 trace. First light in the rear ullage was seen at approximately 2 ms, and, while there was a moderate flame in the rear axial ullage, a small luminous front detached itself and moved forward at approximately 3 ms. At 4 ms, it was apparent that the basepad was starting to burn, since there was an increased brilliance in the area, and some streaming into the radial ullage. At 17 ms, some gases had percolated through the bottom of the charge and exited at the front, and this region of flame grew, as did that generated at the basepad, as time

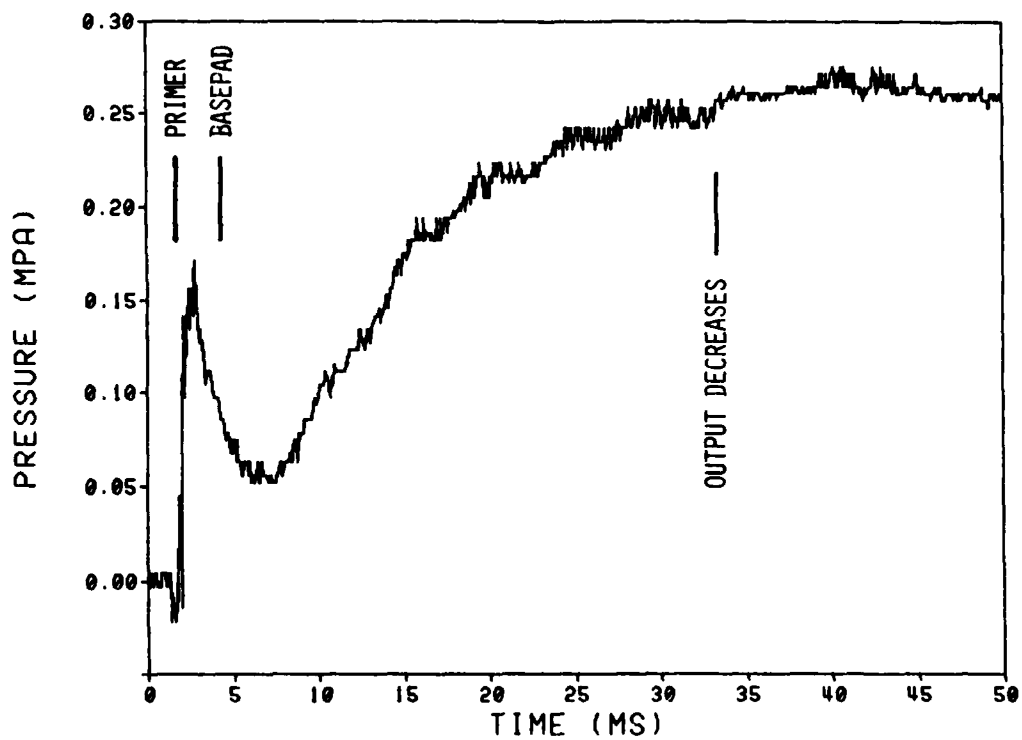

Figure 11. Spindle Pressure, Series I - Live Basepad, Inert Snake and Propellant

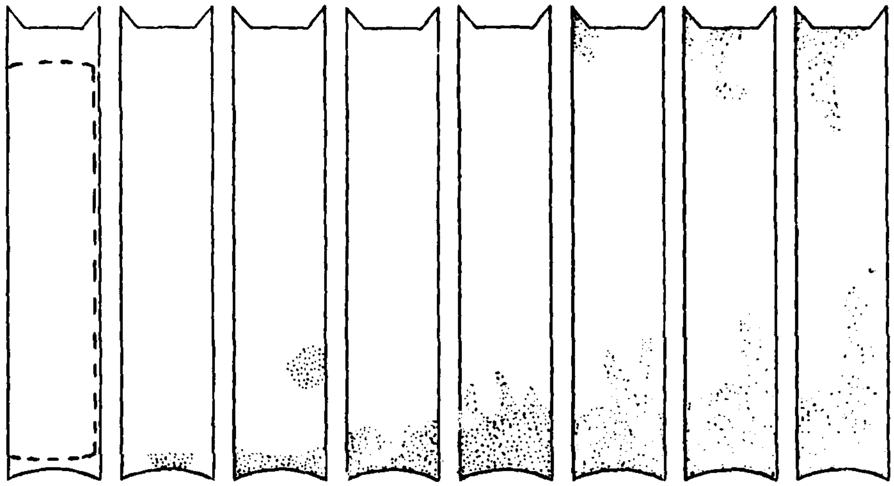

Figure 12. High-Speed Photographic Data, Series I - Live Basepad, Inert Snake and Propellant

progressed. At 23 ms, smoke obscured the outline of the charge, and it had not yet moved perceptibly. At about 33 ms, the output of the basepad area decreased, though it continued to burn, beginning to emit particulate into the flow. The basepad was luminous at times in excess of 100 ms. Also at about 33 ms, a spot in the sidewall, just behind the lead and wax liners, began to burn, but examination after the shot indicated that it did not burn through. No flame was visible through the centercore window at any time during this shot. When the fixture was downloaded at the conclusion of the test, the charge was pressed against the projectile, but the flash reducer bag was intact. The charge was not noticeably compacted. The centercore tube was charred, but remained intact.

The pressure data for the other two Series I shots were not as well behaved as those displayed for the example, and some of the film details were different. Generally, the early details of the primer and basepad functioning were obscured by smoke. One film revealed a flow of gases into the top radial ullage, and a stronger stagnation of gases at the projectile base. In both of the other shots, the two front holes in the plastic window showed some luminosity about 30 ms into the cycle, probably due to stagnation of basepad gases at the closure cap at the forward end of the centercore. As with the example charge, the other two were pressed against the projectile and slightly flattened at the front, but there was not any substantial compaction.

3. <u>Series II - Live Basepad and Snake, Inert Propellant</u>. The P3 pressure trace from an example round is shown in Figure 13, and an abstraction of the photographic data in Figure 14. Again, P3 shows the primer action. As best could be read through the smoke, which obscured many of the early details of these shots, the primer and initial basepad functioning was as described earlier. At 5 ms, the basepad started to burn. At 21 ms, combustion at the rear of the charge was well underway, and the two front window holes showed faint light, but there was no substantial streaming of luminous gases into the radial ullage. At 35 ms, the character of the flame at the rear of the charge changed markedly, with less turbulence and the beginnings of particulate matter in the flow. At the same time faint light appeared at the second and third holes in the centercore windows, indicating a possible transfer of the ignition locus to the snake. The pressure trace also shows the beginning of a change in slope at this time. As Figure 14 shows, the charge continued to produce flame at the base, though its character was different than that prior to 35 ms, and a luminous front traveled down the centercore, in a non-uniform manner. Light did not appear at the holes in sequence from rear to front, either indicating an obscuration by smoke in the centercore, or non-uniform ignition of the snake. To varying degrees depending on axial location, some luminosity was seen between the holes, indicating burning of the centercore tube or escape of gases through the holes. After the window holes shown were illuminated, a wave of increased luminosity seemed to travel through the centercore from front to rear. The front one and rear two window holes were not illuminated. Again, smoke obscured the details of the charge motion, but, upon down-loading, it had been compacted by about 40 mm, and the flash reducer bag was ruptured. The centercore tube remained in place, but it was charred throughout and crumbled at a touch.

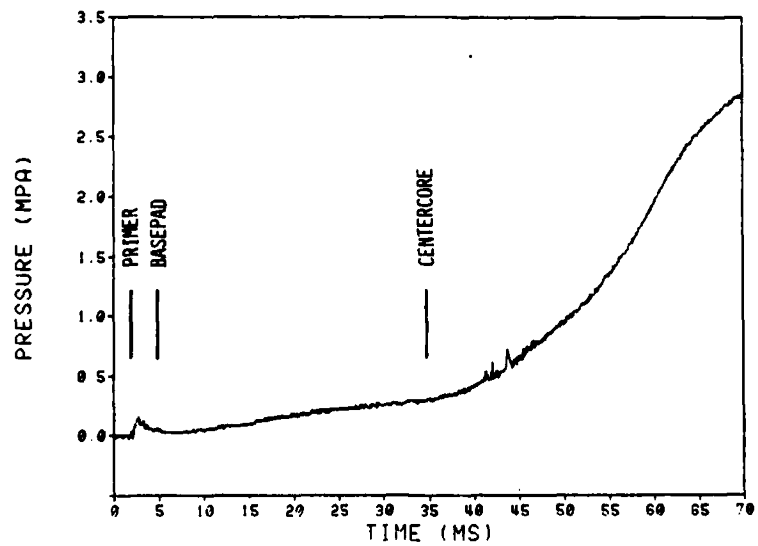

Figure 13. Spindle Pressure, Series II - Live Basepad and Snake, Inert Propellant

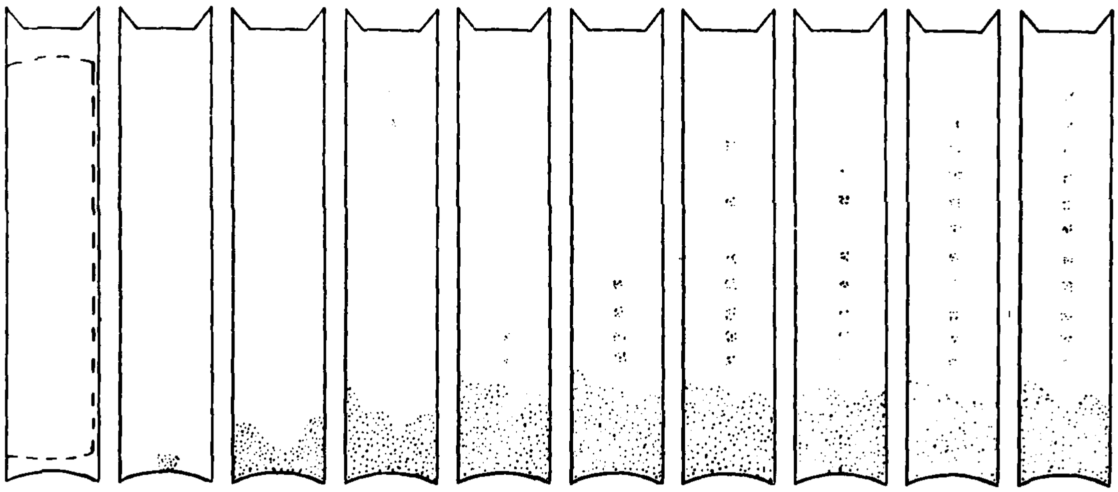

Figure 14. High-Speed Photographic Data, Series II - Live Basepad and Snake, Inert Propellant

The other two shots of Series II reproduced the example on a large scale, though some of the details of the film data were different. One showed substantial streaming of gases from the base area into the radial ullage, while the third was intermediate between the other two. In both other shots, the luminous front propagation down the centercore was non-uniform, the holes lit up out of sequence, luminosity appeared at the front 3-5 holes first, and no flame was seen at the rear hole. These charges were also compacted by about 40 mm.

As an illustration of the vigor with which igniter products can vent into the ullage around the charge, we include a photograph from another test as Figure 15. This was also an M203 charge, not windowed, but constructed with a fully live ignition system and inert propellant. The magnitude of the streaming of the gases is comparable to that observed in one of the Series II shots. It was somewhere between the final two photographs of Figure 15 that the character of the flame observed in the present tests changed from gas to gas and particulate, and the snake was initiated.

4. <u>Series III - Fully Live Charge</u>. The P1 and P3 pressure traces for an example round of this series are shown in Figure 16. The instrumentation was arranged such that P1 recorded the full pressure rise until the fracture of the plastic chamber, and P3 recorded the lower pressure data with more resolution. Figure 17 presents a schematic of data

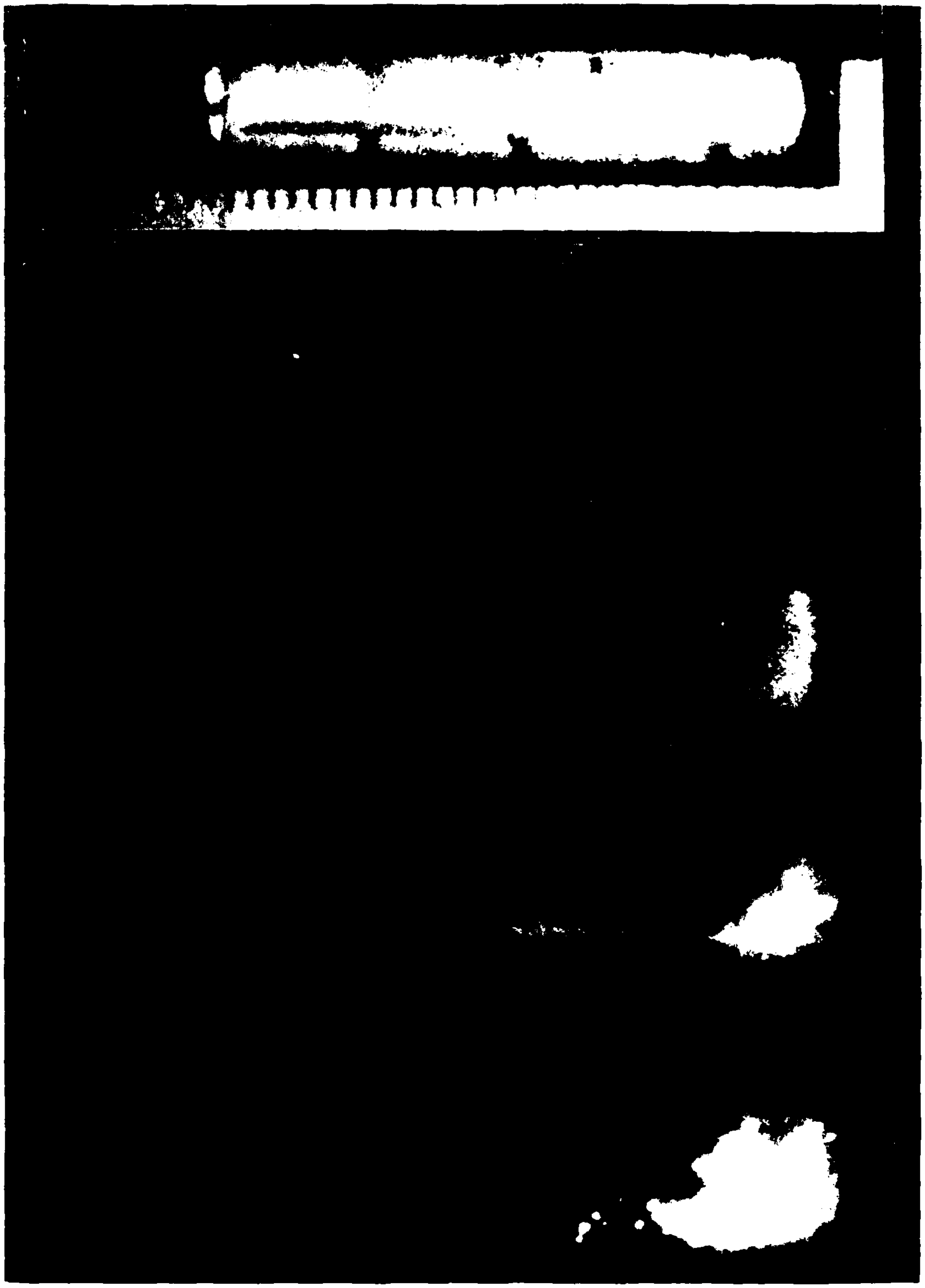

Figure 15. High-Speed Photographic Data, M203 Propelling Charge - Live Basepad and Snake, Inert Propellant

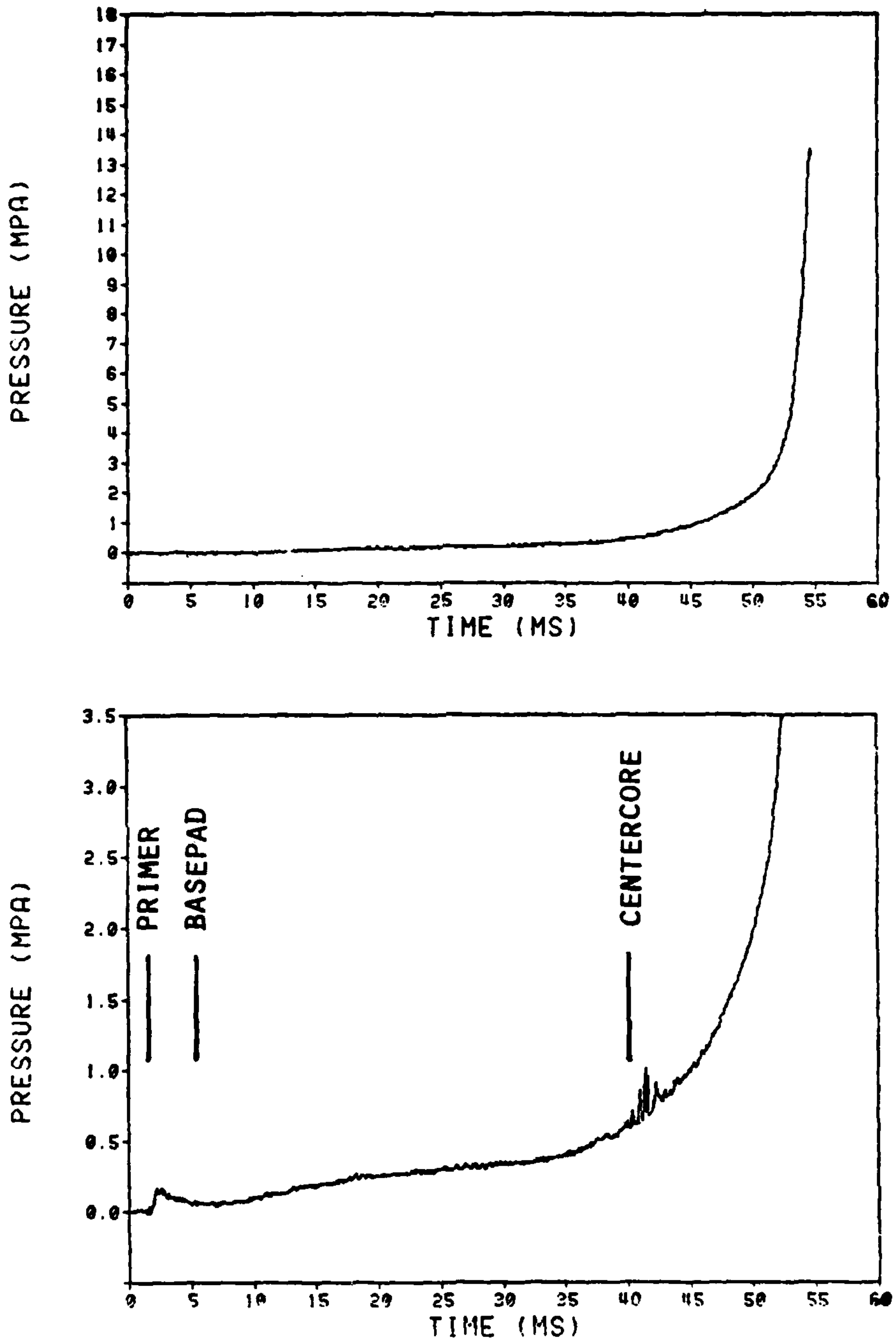

Figure 16. Spindle Pressures, Series III - Fully Live Charge

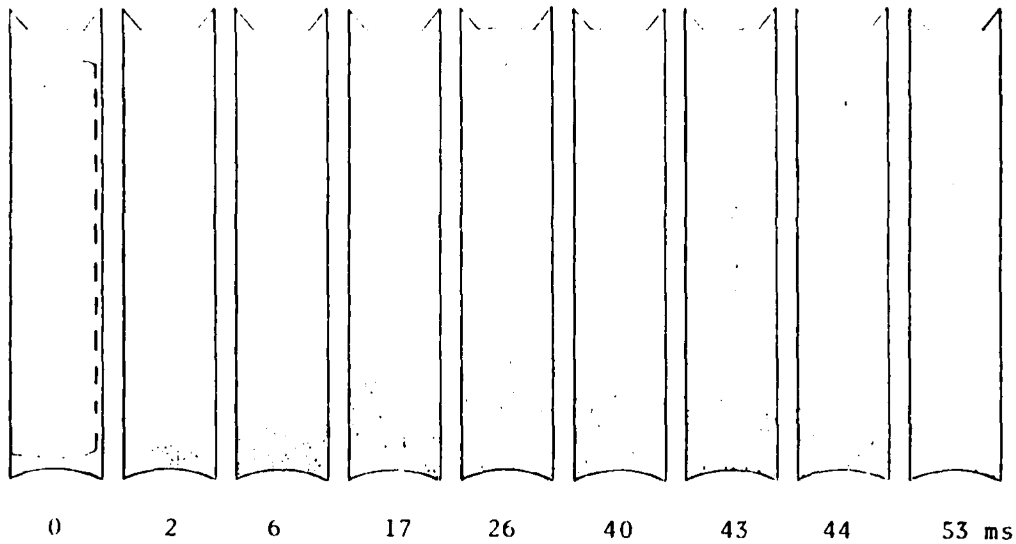

Figure 17. High-Speed Photographic Data, Series III - Fully Live Charge

abstracted from the high-speed films. Again smoke obscured many of the details of the charge movement and the early functioning of the basepad, but the part of the record that could be seen substantially reproduced that seen in the Series I and II shots. At about 2 ms, the first light was seen on the film, and the primer pulse was evident in pressure P3. The basepad began to provide luminous output at about 6 ms, and the base end of the charge continued to burn brightly without substantial streaming into the ullage until about 37 ms. During this time, there was a momentary luminosity at the forward end of the centercore at 26 ms, as was seen earlier, again probably due to a stagnation of basepad gases at the endcap of the centercore. At 36 ms, particulates began to join the flow, and the base area output decreased somewhat. Yet, light was not seen in any of the centercore window holes until 40 ms, and this first light started at the third window position, 51 mm downstream from that observed in the three Series II shots. A reference to Figure 16 shows that the first rear centercore light occurs relatively later with respect to pressure slope change than in the Series II shots. That the rearmost luminosity appears further downstream may be a result of smoke or snake bag material obscuration of the flame, or it may be evidence that local ignition of base propellant grains produce sufficient gas to blow pyrolized products, and a possible ignition site, further downstream. Proceeding through the cycle, all of the window ports except the rearmost three lit up, though in a non-uniform sequence. As in the Series II shots, some luminosity was seen between the holes, perhaps indicative of burning of the centercore tube. The bag ruptured at about 54 ms, just prior to case rupture at approximately 13.5 MPa. The details of the flame in the ullage were slightly different for the other two Series III shots, and the sequence in which the window holes lit up was different, but the behavior of the rear portions of the centercore was substantially the same.

5. Multiple-Increment Charge. One charge each at Zones 5 and 6 was temperature conditioned to 62.8°C and fired in the plastic chamber. A portion of the photographic data for the Zone 5 shot is shown in Figure 18. The top photograph shows the charge prior to firing, with the spindle at the right and the projectile at the left of the figure. Shown next in the figure is the early igniter functioning. After this a mild luminous front oscillated between the spindle and projectile (not shown). As the charge began to burn, it became cocked so that the rear end was lifted off and the forward end remained on the bottom of the chamber. Further into the cycle, a slug of propellant separated from the charge, and was propelled toward the projectile. Each of the seven final photographs of Figure 18 is separated by about 0.4 ms. The plastic tube failed in the frame succeeding the final photograph. The velocity of the slug of propellant at this time was approximately 150 meters per second.

The Zone 6 firing, not shown, displayed the same behavior in the early ignition portion of the cycle. The primary difference in the results from the two tests was that the Zone 6 charge remained integral until tube failure at 16 MPa, and, in fact, did not even move perceptibly. These limited results lend credence to our earlier hypothesis that the given set of conditions of this charge - the brisance of the igniter and base increment, the inertia of the individual forward increments, the ullage - favors separation and movement of the Zone 5 increment but not the Zone 6.

A result of both of the multi-increment tests, and one not shared in many other tests we have conducted, is the optical character of the flame in the ullage. A comparison of the photographs of Figures 15 and 18 serves to illustrate the point. The flame of Figure 15, from the black powder igniter, is a moderate to intense orange as recorded on the color film. The flame produced in the early igniter portions with the CBI-ignited multi-zone charges is the same color, but as the cycle progresses, the flame becomes a very intense white, so much so that the film becomes saturated. Possibly, this is a result of combustion of products liberated as the solid propellant burns. This could happen either by the process discussed earlier, where pyrolized products are carried downstream to burn in the wake from the solid propellant, or it may be a phenomenon akin to secondary flash at the gun muzzle, where a fuel-rich mixture is heated to ignition by the passage of a shock front. Future tests to explore these possibilities will be conducted with different igniters and chambers pre-loaded with nitrogen. Recordings of the flame will be made with infrared film.

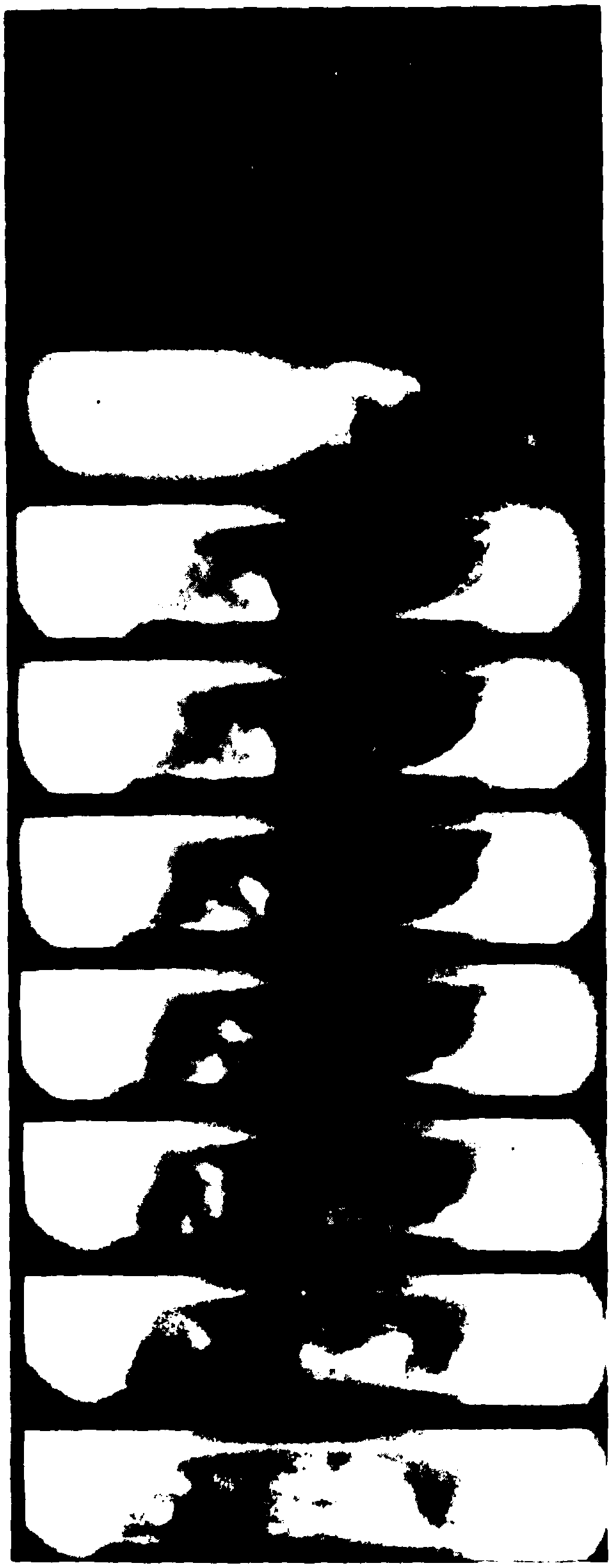

Figure 18. High-speed Photographic Data, 155-mm, XM211 Charge (Advanced Development Concept)

III. CONCLUSIONS

We have collected data that depict the functioning of the top-zone, M203, Zone 8S, igniter system, and provided a correlation between experimentally measured variables such as pressure and flame propagation in the igniter, charge and ullage. In addition, we have provided the first indication of the dynamics of a multiple-increment charge during ignition and flamespread. Unfortunately, the variability of performance measured up to that described in our discussion of possibilities earlier. We have seen that, though some elements in an ignition train may perform reproducibly, as does the basepad of the M203, others are not so well behaved. The reproducibility of the transfer of the ignition stimulus to the snake in the centercore is particularly suspect, due probably to intervening material, and even when burning of the snake commences, the evidence indicates that it is grossly non-uniform, with first light seen at a depth away from the base. The multi-zone charge behaved differently depending on the zone fired, and the ignition-induced dynamics of the charge movement could provide a deleterious environment for the projectile.

In summary, it is important to call attention again to the fact that all parts of a charge and its loading geometry need be considered as part of a total ignition system. Not only the igniter proper, but the bag, liners, flash reducers, and ullage distribution all profoundly affect the complex, early flows of ignition and combustion gases. And the character of the flame seen in some of these studies once again raises the question of a criterion to use for a measure of ignition itself. Though we will undoubtedly make great strides in our modeling capabilities by pursuits such as consideration of the multi-dimensional aspects of the problem, it hardly seems likely that we will enjoy complete success without a detailed improvement in the treatment of all these ignition-related parameters.

ACKNOWLEDGMENTS

We are grateful to Mr. A. Koszoru for fabricating the charges used in this study, and to Messrs. J. Bowen, J. Hewitt, J. Stabile, and A. Koszoru for assistance in conducting the firing program.

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